ECOLOGICAL NETWORK ANALYSIS OF BENTHIC-PELAGIC FOOD WEB COUPLING IN SHALLOW WATER OF COASTAL ANDHRA PRADESH, INDIA

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INTRODUCTION

Benthic organisms, also called "**benthos**", comprise of the community of organisms that occupy the intertidal coastal zones and sediment layers of the marine or freshwater water bodies.

There are different modes of classification of benthos based on their size, trophic role, type of substratum, type of substratum affinity, etc. The mostly used classification is a combined form of their size-macrobenthos (>0.5mm), meiobenthos (0.04mm-0.5mm), microbenthos (<0.04mm) and trophic role-phytobenthos (can photosynthesize) and zoobenthos (cannot photosynthesize), such as microphytobenthos or macrozoobenthos.

Light attenuation in the deep oceans prevents ample light from reaching the sediment layer and thus prevents the growth of phytobenthos. Thus, the benthic food chain is sustained by the dead and decaying organic matter that drifts down from the water column, especially in deep sea systems.

In shallow ecosystems where light reaches the sediment, that is, in the euphotic zone, phytobenthos can flourish and photosynthesize. Thus, primary productivity of the benthic ecosystem is usually light limited and not nutrient limited. Though, macrophytobenthos are also present, microphytobenthos has a much higher contribution to the productivity of the benthic system.

The benthic food chain predominantly comprises of detritivores and scavengers as primary consumers. Filter feeders such as sponges and bivalves (seen to occupy hard sandy bottoms) and deposit feeders such as polychaetes (seen to populate soft bottoms) are other prominent consumers.

Filter feeders and deposit feeders along with fishes such as demersal fishes (that live and feed near or in the sediment zone) play a huge role in exchange of nutrients and energy between the benthic food web and the pelagic food web. This exchange of nutrients and energy between two distinct food webs is known as benthic-pelagic coupling. The ecological role of benthic pelagic coupling is as follows-

- The benthos especially microphytobenthos compete with denitrifying bacteria for inorganic nitrate and prevents its loss from the system. This sequestered nitrate again re-enters the pelagic food chain when organic matter is resuspended from the sediment due to tidal action or bioturbation or when pelagic fishes feed on benthic organisms. These re-introduced nutrients are responsible for boosting the primary productivity of the system.
- Marine benthic diatoms are abundant and ubiquitous in terms of ecosystems and water chemistry and are sensitive to nutrient variation as well as their short life span allows short term stresses to be monitored (Desrosiers et al., 2013). Stresses which affect the pelagic food web are manifested in the benthic food chain through these ecological linkages.
- Linkage between pelagic and benthic food webs result in a reticulate food web that encompasses the whole aquatic system and is responsible for increasing the secondary productivity as well because they represent a highly nutritious food source for higher consumers (Schindler and Scheuerell, 2002; Vadeboncoeur et al., 2003; Vander Zanden and Vadeboncoeur, 2002).

PREVIOUS STUDIES & LACUNAE

Till date, most studies on trophic dynamics of aquatic systems were based on a conceptual model of linear pelagic food chain comprised of three or four functional tropic levels- phytoplankton, zooplankton, fishes and piscivorous fish (Carpenter et al., 1985; Mittelbach et al., 1995) which consider phytoplankton as the only relevant primary producer; or the benthic and pelagic production processes have been treated as separate (Vadeboncoeur et al., 2002). Most studies regarding benthos were focused on the productivity of microphytobenthos and the factors affecting it (Guarini et al., 2008, 2000a, 2000b; Hochard et al., 2010; Pinckney and Zingmark, 1993).

There have been a few modelling studies regarding the benthic food chain (Ascione, 2014; Baretta et al., 1995; Kohlmeier and Ebenhöh, 2007; Lindeboom et al., 1989) but nutrient transfer is not limited by only prey-predator interactions; the decomposition and mineralization processes occurring in the sediment layers affect and is affected by the benthic food web dynamics. Changes in benthic-pelagic coupling and balance between detritus and living matter affects and is affected by changes in food web dynamics. In the Indian front benthic food web model has been used to study the effect of anthropogenic stress in a reclaimed island by Ray et al., (2000) and later used to compare the dynamics of the reclaimed island with a pristine island by Ray (2008).

This approach neglects the potential role of benthic production and processes at the whole-ecosystem level (Vadeboncoeur et al., 2002) and the diverse ways in which benthic, pelagic, and riparian habitats can be energetically and dynamically linked (Schindler and Scheuerell, 2002). Previous studies on benthic-pelagic coupling are as follows-

- Tilstone et al.(2000) - Nutrients exported to the sediment, when re-introduced to the water column in the form of re-mineralised inorganic nutrients creates potential for high primary productivity in the water column even when terrestrial nutrient input is low.
- Schindler and Scheuerell (2002), Vander Zanden and Vadeboncoeur (2002) and Vanni (2002) – fishes were shown to be the most important mobile carriers that connected both the food webs.

- Vadeboncoeur et al. (2002) – showed that the ecology of an aquatic system is determined by the benthic-pelagic coupling and a system can be benthic-dominated or pelagic-dominated depending on the coupling dynamics.
- Zanden et al. (2005) – showed that benthic food chain intensified trophic interactions of the entire system.
- Granek et al. (2010) and Seitz et al. (2013) - multiple and interacting benthic–pelagic coupling processes support essential ecosystem functions, such as production and energy transfer in food webs, biogeochemical cycling and provisioning of fish nursery areas.
- Baustian et al. (2014) – described the different mechanisms involve in benthic-pelagic coupling and grouped them into three classes: organism movement, trophic interactions and biogeochemical cycling.
- The effects of anthropogenic stress on different mechanisms of coupling was studied by many authors over the years (Chandra et al., 2005; Griffiths et al., 2017; Matsuzaki et al., 2007).

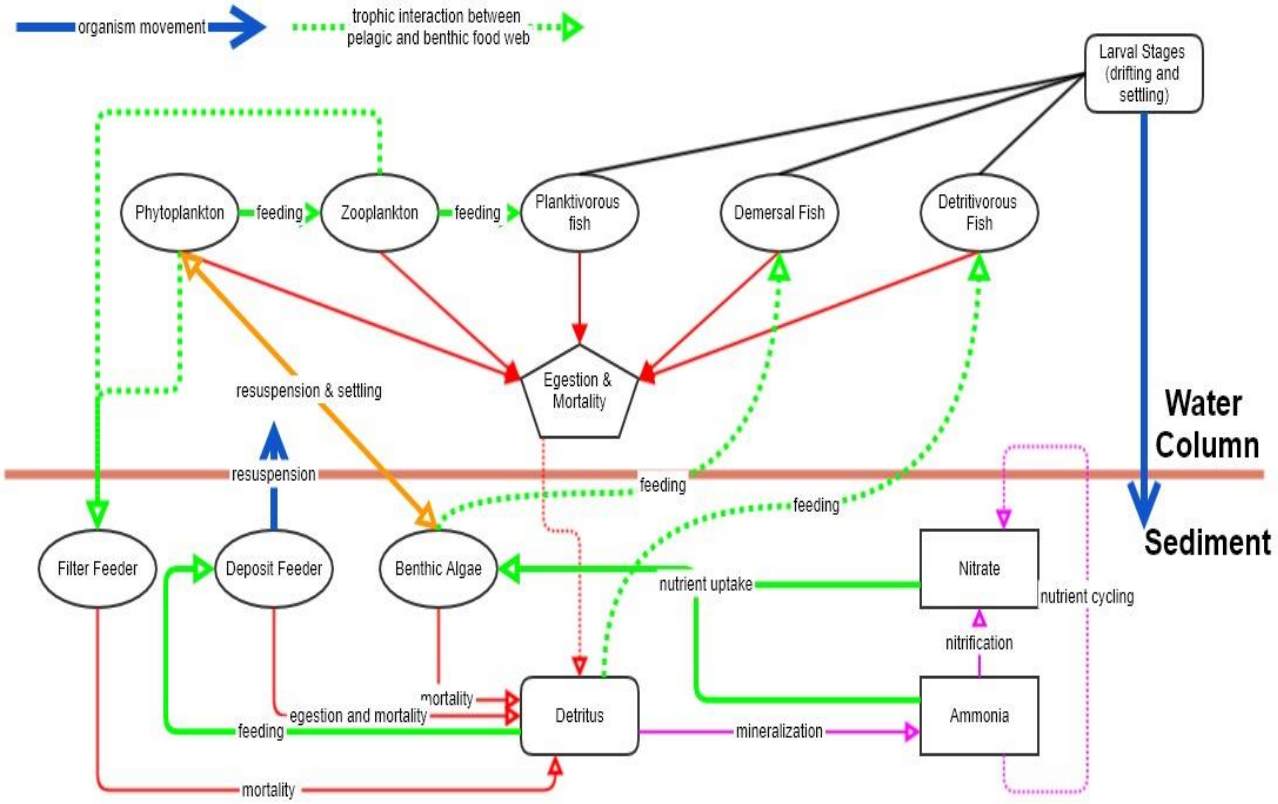
Benthic studies in the Indian scenario have mainly focused on the productivity of the benthic food chain and factors influencing the same and the distribution of benthic organisms (Ganesh and Raman, 2007; Joydas and Damodaran, 2009). Studies on microphytobenthos have mainly been done in the temperate regions; some notable works in this field in India are the works of Sanilkumar et al., (2009) and Bhaskar and Bhosle (2008).

Ecological network analyses have been applied in various situations for example, studying the trophic structure of a reservoir (Banerjee et al., 2016), in determining the robustness of a reservoir ecosystem (Banerjee et al., 2017) and also of an estuarine ecosystem (Mukherjee et al., 2015). Further examples of application of ENA include determination of keystone species (Banerjee et al., 2017). Recent study by Rakshit et al., (2017) using static models for temporal comparison of trophic structure of the Hooghly-Matla estuarine system considers a few benthic compartments as well. However, modelling studies including benthic-pelagic coupling have been negligible.

OBJECTIVES

The objectives of this present study are as follows-

1) Development of a benthic food web based model with special emphasis on microphytobenthos to understand the benthos population dynamics at the community level of organisation in the shallow waters of east coast of India.
2) Integrating the benthic food web model with a pelagic food web model to understand how the benthic food web affects the productivity and dynamics of the whole system.
3) Identifying the organisms that facilitate coupling in the system and determining how they react to anthropogenic stress.
4) Identification of the coupling linkages that are the most sensitive based on their reaction to stress and their effects on the food web of the entire system.



A diagrammatic representation of an integrated benthic and pelagic food web model showing different mechanisms of coupling (as indicated by the different arrows)

METHODOLOGY

Variations in water quality and sediment quality will be studied by measuring the changes in different chemical and physical parameters such as dissolved oxygen content, organic and inorganic nitrogen content, carbon content, temperature and pH. Biomass content of each biotic compartment (phytobenthos, zoobenthos, phytoplankton, fish, etc) will be measured in terms of nitrogen content or carbon content. The data will be collected monthly or fortnightly for a period of one year and used to develop the benthic model. Data collected in a second year will be used to validate the model.

A pelagic food web model will be modified based on the constraints of the selected field and integrated with the developed benthic model; the changes in productivity will be studied.

Organisms coupling the benthic and pelagic systems will be identified from the integrated model. Anthropogenic stress would be theoretically simulated in the model to study how they affect the coupling linkages and how these changes are transmitted throughout the system through these linkages.

Static modelling approach would be used to formulate the proposed model.

In this particular modelling approach, the model is represented by a network which is a collection of nodes interconnected by arcs. Nodes represent the biotic and abiotic components of the food web. The connecting arcs are directed and weighted (that is they indicate unidirectional flow of a certain magnitude) and are termed as edges.

Of the various static modelling softwares available, Ecopath with Ecosim (EwE) will be used for development of the food web model.

The basic assumption of EwE is based on the following two controlling equations viz. (1) Production = Catch + Predation + Net Migration + Biomass Accumulation + Other Mortality; and (2) Consumption = Production + Respiration + Unassimilated Food.

$$B_i . \left(\frac{P}{B}\right)_i . EE_i - \sum_{j=1}^{i} B_j . \left(\frac{Q}{B}\right)_j . DC_{ji} - EX_i = 0$$

Where, $\boldsymbol{B_i}$ represents biomass of the group ***i***, $\boldsymbol{(P/B)_i}$isproduction to biomass ratio for group ***i***and is equal to total mortality coefficient***Z***at steady state,$\boldsymbol{EE_i}$ is the ecotrophic efficiency of group ***i***, $\boldsymbol{B_j}$ is the biomass for predator ***j***, $\boldsymbol{(Q/B)_j}$ is theratio of consumption to biomass for predator***j***, $\boldsymbol{DC_{ji}}$ is the proportion of diet of ***j*** obtained from ***i***, $\boldsymbol{EX_j}$represents the export of group ***j*** and ***i*** and ***j*** are the number of prey and predator groups in the system respectively.

Ecopath routine of the EwE modelling technique has four input labels in the 'basic input' tab (required for providing the standing stocks of components i.e. *B* and their *P/B*, *Q/B* and *EE*) and on providing at least three of them for each individual component, Ecopath can calculate the fourth based on the network structure and flows (defined by the diet matrix or flow matrix *F*) through utilization of parameterizing algorithms.

After formation of the model ecological network analyses would be used to estimate different ecological indices such as Total System Throughflow (***TST***), Finn Cycling Index (***FCI***), Developmental Capacity (***C***), Ascendancy (***A***), Keystoneness Index ($\boldsymbol{KS_i}$), Robustness etc.

PROBABLE OUTCOME

The coastal margins of the world's landmasses are the most populated and most polluted areas of the world and the model developed could be used to monitor the effects of different stressors on the aquatic ecosystems. Benthic organisms especially microphytobenthos integrate the effect of stressors on the water column as well as the sediment through their linkages with the pelagic food web and thus act as highly sensitive indicators.

The benthic food web also increases both the primary and secondary productivity of the system and helps the system in maintaining its integrity and resilience.

Studies relating the benthic and pelagic food web models have been few. With the results of the present study, it will be possible to achieve a better understanding of the benthic food web, its contribution to the productivity of the system and how the benthic and pelagic food webs are coupled. The effect of different anthropogenic stressors on the system could be studied over a long run and management practices to mitigate these effects could be implemented as a result.

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